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0329839.5 23 DEC 2003

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

The BOC Group plc, Chertsey Road, Windlesham, Surrey, GU20 6HJ

Patents ADP number *(if you know it)* 884627002

If the applicant is a corporate body, give the country/state of its incorporation England

4. Title of the invention

VACUUM PUMP

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

Andrew Steven BOOTH

The BOC Group plc, Chertsey Road, Windlesham, Surrey, GU20 6HJ

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Andrew Steven Booth
(01276) 807612

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VACUUM PUMP

The invention relates to a vacuum pump.

Vacuum processing is commonly used in the manufacture of semiconductor devices to deposit thin films on to substrates. Typically, a processing chamber is evacuated using a vacuum pump to a very low pressure, which, depending on the type of process, may be as low as 10^{-6}mbar, and feed gases are introduced to the evacuated chamber to cause the desired material to be deposited on one or more substrates located in the chamber. Upon completion of the deposition, the substrate is removed from the chamber and another substrate is inserted for repetition of the deposition process.

Significant vacuum pumping time is required to evacuate the processing chamber to the required pressure. Therefore, in order to maintain the pressure in the chamber at or around the required level when changing substrates, transfer chambers and load lock chambers are typically used. The capacity of the load lock chamber can range from just a few litres to several thousand litres for some of the larger flat panel display tools.

The load lock chamber typically has a first window, which can be selectively opened to allow substrates to be transferred between the load lock chamber and the transfer chamber, and a second window, which can be selectively opened to the atmosphere to allow substrates to be inserted into and removed from the load lock chamber. In use, the processing chamber is maintained at the desired vacuum by the processing chamber vacuum pump. With the first window closed, the second window is opened to the atmosphere to allow the substrate to be inserted into the load lock chamber. The second window is then closed, and, using a load lock vacuum pump, the load lock chamber is evacuated until the load lock chamber is at substantially the same pressure as the transfer chamber, typically around 0.1mbar. The first window is then opened to allow the substrate to be transferred to the transfer chamber. The transfer chamber is then

evacuated to a pressure at substantially the same pressure as the processing chamber, whereupon the substrate is transferred to the processing chamber.

When vacuum processing has been completed, the processed substrate is transferred back to the load lock chamber. With the first window closed to maintain the vacuum in the transfer chamber, the pressure in the load lock chamber is brought up to atmospheric pressure by allowing a non-reactive gas, such as air or nitrogen, to flow into the load lock chamber. When the pressure in the load lock chamber is at or near atmospheric pressure, the second window is opened to allow the processed substrate to be removed. Thus, for a load lock chamber, a repeating cycle of evacuation from atmosphere to a medium vacuum (around 0.1mbar) is required.

Load lock pumps are typically oil-free in their vacuum chambers, as any lubricants present in the vacuum chambers might cause contamination of the clean environment in which the vacuum processing is performed. For example, the "iH" series of BOC Edwards "dry" vacuum pumps comprise a dry backing, or roughing, pump in combination with a single stage Roots mechanism booster, or blower, pump mounted above the dry pump. Backing pumps are commonly multi-stage positive displacement pumps employing inter-meshing rotors. The rotors may have the same type of profile in each stage or the profile may change from stage to stage.

For the larger flat panel display tools, the pumping speed of the load lock pumps needs to be high, for example, up to 2000m^3/hour. Whilst a load lock pump formed from a dry backing pump using Roots and Northey mechanisms, in series with a Roots booster pump can provide such a pumping speed, the relatively large foot-print of the pump combination, together with the level of noise and vibration generated during use, typically lead to the load lock pump being located remote from the processing tool, for example, in a basement. As well as being inconvenient to the user, relatively long runs of large diameter pipe work are

needed to connect the load lock pump to the load lock chamber, significantly increasing installation costs.

It is an aim of at least the preferred embodiments of the present invention to solve these and other problems.

In summary, in accordance with the present invention at least one of the booster pump and the backing pump in the conventional pumping arrangement is replaced by a vacuum pump comprising a multi-stage centrifugal compressor system. In one embodiment, both the booster pump and the backing pump are replaced by a single vacuum pump exhausting to atmosphere. In a second embodiment, the booster pump is provided by a similar vacuum pump to the first embodiment, having a reduced number of compressor stages, backed by a backing pump. This backing pump may be a conventional backing pump, or, in accordance with a third embodiment, may be a vacuum pump comprising a multi-stage centrifugal compressor system exhausting to atmosphere. Such a backing pump may be provided with a conventional Roots booster pump.

Due to the reduced levels of size, noise and vibration associated with a centrifugal compressor system in comparison to the conventional dry pumps, replacing one or both of the conventional backing and booster pumps with a pump comprising a multi-stage centrifugal compressor mechanism can enable at least part of the pumping arrangement to be mounted on the processing tool, thereby potentially avoiding the expensive long runs of large diameter pipe work.

Thus, in a first aspect, the present invention provides a vacuum pump comprising a multi-stage centrifugal compressor mechanism for receiving fluid to be pumped and exhausting pumped fluid substantially at atmospheric pressure.

The pump preferably comprises a pump housing and a rotatably mounted drive shaft, with each stage of the compressor mechanism comprising a respective impeller mounted on the drive shaft and a respective stator located on the inner

wall of the pump housing. Each impeller preferably has on one side thereof a plurality of vanes or blades extending between the inner periphery and the outer periphery thereof. Each blade preferably follows a curved path. For example, at the exhaust stages of the compressor mechanism, the impellers may have forward-swept blades or radial blades. At the inlet stages of the compressor mechanism, the impellers may have back-swept blades. To facilitate manufacture, each stator preferably comprises a disc integral with a respective part of the pump housing.

Fluid that is compressed by the compressor mechanism typically becomes hot. In order to cool fluid pumped by the compressor mechanism, particularly at the exhaust stages, the stators preferably comprise a plurality of cooling fins on one side thereof, typically on the side of the stator facing away from the impeller. In order to cool the vacuum pump housing, to which heat will be transferred by the pumped fluid, a pump cooling system may also be provided, for example, in the form of a cooling jacket extending about at least the exhaust stages of the compressor mechanism.

To avoid any problem associated with oil back-streaming from the pump, the drive shaft is preferably supported at the ends thereof by lubricant-free bearings, for example, magnetic bearings.

Centrifugal compressor mechanisms are susceptible to surging of pumped fluid when the specific flow rate of the pumped fluid through a stage of the compressor mechanism is relatively low. The surging manifests itself in a backflow of fluid into the compressor impeller, and adversely affects the efficient operation of the vacuum pump, and in extreme conditions, may actually damage the pump. In view of this, in one preferred embodiment a proportion of the pumped fluid exhaust from a compressor stage is returned back to the inlet of the stage and recirculated when surging is imminent. In another preferred embodiment, a flow of purge gas is supplied to the inlet of the stage. As a result, the rate of flow through the

compressor mechanism can be maintained at a value above that at which surging will occur.

In the preferred arrangement, each stage comprises a fluid chamber within which the impeller rotates during use of the pump. At least one of the fluid chambers comprises an inlet through which a first fluid stream enters the chamber, an outlet through which pumped fluid is exhausted from the chamber, and, intermediate the inlet and the outlet, a fluid port through which a second fluid stream enters the chamber. In order to inhibit surging, the pump comprising means for controlling the flow of fluid through the fluid port and thereby control the rate of flow of fluid through the outlet to a subsequent stage of the compressor mechanism.

As this is an important feature of the present invention, in a second aspect the present invention provides a vacuum pump comprising a multi-stage centrifugal compressor mechanism, at least one stage of the compressor mechanism comprising a fluid chamber having an inlet through which a first fluid stream enters the chamber, an outlet through which pumped fluid is exhausted from the chamber, and, intermediate the inlet and the outlet, a fluid port through which a second fluid stream enters the chamber, the pump comprising means for controlling the flow of fluid through the fluid port and thereby control the rate of flow of fluid through the outlet to a subsequent stage of the compressor mechanism.

In the first preferred embodiment, conveying means for conveying the second fluid stream to the fluid port is arranged to return a stream of pumped fluid to the chamber through the fluid port. For example, the conveying means may comprise a fluid passage extending between stages, preferably between fluid ports of adjacent stages, of the compressor mechanism.

The fluid passage may extends through the pump housing or, alternatively, through the pumping stages of the compressor mechanism. In this alternative, each chamber preferably comprises, intermediate the inlet and the outlet, a first

fluid port through which pumped fluid enters the chamber and a second fluid port through which pumped fluid exits the chamber, the fluid passage passing between the first fluid port of one chamber and the second fluid port of a second chamber. The fluid passage may pass through means axially separating adjacent chambers of the compressor mechanism, for example, one or more discs mounted on the inner wall of the pump housing, with the first and second fluid ports being preferably co-axial.

In the other preferred embodiment, the conveying means is arranged to convey a stream of purge gas, such as air or nitrogen, to the chamber through the fluid port.

The control means preferably comprises valve means in fluid communication with said conveying means. The valve means may comprise a series of valves individually controllable to control fluid flow through respective fluid passages connecting adjacent stages of the compressor mechanism, a spool valve for controlling fluid flow through each fluid passage, or separate valves for controlling a purge flow into one or more of the various stages. In order to control the valve means, a pressure sensor may be provided to monitor the pressure of fluid passing through the pump inlet, a signal from the inlet sensor being supplied to a control system which controls the opening and closing of the valve means in order to inhibit surging. In addition, or alternatively, pressure sensors may be provided within the pump to monitor pressure fluctuation within the pump, and thus detect the onset of surging.

In order to reduce the temperature of the fluid entering, or being returned to, a pumping stage, the pump preferably comprises means for cooling the second fluid stream.

Where the pump is to be used as a backing pump, the pump may consist of such a multi-stage centrifugal compressor mechanism, in combination with a suitable booster pump. Such a booster pump may be provided by a pump comprising a multi-stage centrifugal compressor mechanism downstream from a multi-stage

molecular drag mechanism, the number of stages of the compressor mechanism (for example, two) being smaller in the booster pump than in the backing pump (for example, six or seven). Alternatively, the conventional combination of booster and backing pumps may be replaced by a single pump, this pump comprising a multi-stage (for example, six or seven stage) centrifugal compressor mechanism downstream from a multi-stage (for example, four stage) molecular drag mechanism. Thus, the present invention also provides a vacuum pump comprising a multi-stage centrifugal compressor mechanism and, upstream therefrom, a multi-stage molecular drag mechanism arranged to receive fluid to be pumped and to exhaust pumped fluid to the radial flow compressor mechanism. The molecular drag mechanism preferably comprises a multi-stage Holweck mechanism having a plurality of channels arranged as a plurality of helixes. The drag stages may be arranged in series, in parallel for maximum pumped volume, or combination of both.

Preferred features of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a cross-section through a first embodiment of a vacuum pump;

Figure 2 is a cross-section through a second embodiment of a vacuum pump, which is similar to that of figure 1 with a different surge control mechanism; and

Figure 3 is a cross-section through a third embodiment of a vacuum pump, which is similar to that of figure 1 without a drag mechanism.

With reference to figure 1, a vacuum pump 10 suitable for evacuating a load lock chamber comprises a housing 12 having three parts 14, 16, and 18. An inlet 20 for the pump 10 is located in the first part 14 of the housing 12, and an exhaust 21 for the pump 10 is located in the third part 18 of the housing 12.

The first part 14 of the housing 12 houses a multi-stage molecular drag pumping mechanism 22. As illustrated in figure 1, in this embodiment the molecular drag pumping mechanism is provided by a four-stage Holweck mechanism 22, although any suitable number of pumping stages may be provided. The rotor of the Holweck mechanism 22 comprises two carbon-fibre cylinders 24, 26, mounted concentrically on a disc-like impeller 28 integral with or, as illustrated, mounted on a rotatable shaft 30. The shaft 30 is supported at each end by lubricant free bearings (not shown), preferably magnetic bearings, and is driven by a motor 31 housed by the third part 18 of the housing 12.

Each cylinder 24, 26 of the Holweck mechanism 22 has smooth inner and outer surfaces. The stator of the Holweck mechanism comprises a plurality of cylinders 32, 34 and 36 concentrically arranged with and surrounding the rotor cylinders 24, 26, the outermost cylinder 36 being provided by the first part 14 of the housing 12. Helical grooves are formed on the outer surfaces of the innermost stator cylinder 32, the inner and outer surfaces of the middle stator cylinder 34 and the inner surface of the outermost stator cylinder 36 to define co-axial helical fluid channels 38, 40, 42, 44, which receive fluid from the pump inlet 20 and exhaust pumped, compressed fluid to a common exhaust port 48 through openings 50 formed in the disc-like impeller 28.

The second part 16 of the housing 12 houses a multi-stage centrifugal compressor mechanism 52. In the embodiment shown in figure 1, the compressor mechanism 52 comprises seven pumping stages. Each pumping stage comprises a rotor in the form of an impeller 54 mounted on the shaft 30. Each impeller 54 has a plurality of blades or vanes 56 located on the upper surface (as shown in figure 1) of the impeller 54. At the inlet stages of the compressor mechanism 52, the blades 56 are backward-swept blades or radial blades, and at the outlet stages of the compressor mechanism 52, the blades 56 are forward-swept blades.

Each impeller 54 is mounted for rotation within a fluid channel 58. As illustrated in figure 1, the fluid channels 58 are separated by a series of discs 60 co-axially

mounted on the inner wall of the second part 16 of the housing 12. Apertures 62 in the discs 60 provide the inlets and the outlets for the first six pumping stages and the inlet of the seventh, final pumping stage, which exhausts fluid from the compressor mechanism 52 via pump exhaust 21.

The second part 16 of the housing 12 may be conveniently provided by a plurality of co-axial rings 16a, 16b, 16c, 16d, 16e, and 16f. A disc-like stator 64 for each of the first six pumping stages is integral with a respective ring, and comprises a plurality of cooling fins 66, provided on the side of the stator 64 facing away from the impeller 54 of that pumping stage, for cooling fluid passing through the pumping stage. In order to cool the housing 12, to which heat will be transferred by the fluid pumped by the compressor mechanism 52, a pump cooling system (not shown) may also be provided, for example, in the form of a cooling jacket extending about at least the second part 16 of the housing 12.

In use, the motor is activated to rotate the shaft 30 at a high speed, typically in the range from 30,000 to 80,000 rpm. Fluid enters the pump 10 through the inlet 20, and passes in turn through the Holweck mechanism 22 and compressor mechanism 52 before being exhausted from the outlet of the pump 10 at a pressure at or around atmospheric pressure. With the arrangement shown in figure 1, a pressure less than 1 mbar, typically at or around 0.1mbar, can be generated in a load lock chamber connected to the inlet 20 of the pump 10.

In order to inhibit surging within the compressor mechanism 52 at relatively low flow rates, the pump 10 is provided with a surge control mechanism for selectively increasing the rate of flow of fluid through one or more of the pumping stages of the compressor mechanism 52. In the first embodiment shown in figure 1, a fluid port 68 is provided in each of the rings 16a, 16b, 16c, 16d, 16e, 16f, each port 68 extending radially through the ring to allow a stream of fluid to be injected into the fluid channel 58. This stream of fluid may be provided by any suitable source. In a first example, the fluid ports 68 of adjacent pumping stages may be connected via an arrangement of conduits located to one side of the pump 10, the conduits

containing one or more valves for selectively opening the conduits to allow pumped fluid from one pumping stage to flow from the fluid port 68 of that stage to the fluid port 68 of the adjacent upstream pumping stage, thereby increasing the rate of flow of fluid through the inlet to the pumping stage. In a second example, a stream of purge gas, such as nitrogen or air, may be selectively supplied from a suitable source to one of more of the fluid ports 68 in order to increase the rate of flow of fluid through one or more of the pumping stages.

In a third example, as illustrated in figure 2, a passage 70 for pumped fluid may be provided through the pumping stages of the compressor mechanism 52 in addition to, or as an alternative to, providing fluid ports 68. The passage 70 is defined by a series of co-axial apertures 72 formed in the discs 60 co-axially mounted on the inner wall of the second part 16 of the housing 12. A spool valve 74 is provided for selectively opening and closing the apertures 72 to control the flow of fluid through the passage 70. As illustrated, the spool valve 74 may be shaped so that movement of the valve 74 causes all of the apertures 72 to be opened simultaneously to allow pumped fluid to flow through the apertures 72 to adjacent upstream pumping stages. Alternatively, the spool valve 74 may be shaped so that movement of the valve 74 causes each of the apertures 74 to be opened in turn, starting, for example, with the aperture 74 connecting the exhaust pumping stages of the compressor mechanism 52.

In order to control the valves in any of these three examples, a pressure sensor may be provided to monitor the pressure of fluid passing through the pump inlet 20. A signal from the inlet sensor may be supplied to a control system, which controls the opening and closing of the, or each, valve in order to inhibit surging. In addition, or alternatively, pressure sensors may be provided within the pump 10 to monitor pressure fluctuation within the pump, and thus detect the onset of surging. Motor current may also be used to indicate shaft torque and power, and thus an estimation of inlet pressure.

As the pumps illustrated in figures 1 and 2 exhaust fluid at or around atmospheric pressure, each pump 10 would be suitable for replacing both the conventional booster and backing pump used for evacuating a load lock chamber. Due to the reduced size of the pump 10 relative to the size of the conventional combination of booster and backing pumps, and due to the reduced noise and vibration levels associated with the pump 10, the pump 10 may be conveniently mounted on the side of the processing tool.

By reducing the number of stages of the compressor mechanism 52, to, say, two stages, the pump 10 can be suitable for use as a booster pump. Figure 3 illustrates an embodiment of a backing pump 100 which would be suitable for use with such a booster pump, or any conventional booster pump. The backing pump 100 is similar to the pump 10 illustrated in figure 1, with the exception that the backing pump 100 does not require a drag mechanism as the fluid entering the backing pump 100 would be at a higher pressure than that entering the pump 10. In other words, the backing pump 100 comprises a multi-stage compressor mechanism 152 for receiving fluid from the pump inlet 120 and exhausting pumped fluid at or around atmospheric pressure from pump outlet 121. The compressor mechanism 152 of the backing pump 100 is similar to the compressor mechanism 52 of the pump 10, and so is not described in further detail here.

In summary, two vacuum pumping arrangements are described for evacuating a load lock chamber. In the first arrangement, a single pump comprises a multi-stage molecular drag stage and a multi-stage centrifugal compressor mechanism exhausting pumped fluid at atmospheric pressure. In the second arrangement, a booster pump is provided in series with a backing pump. The booster pump is similar to the pump of the first arrangement, but with a reduced number of compressor mechanism stages. The backing pump also comprises a multi-stage centrifugal compressor mechanism exhausting pumped fluid at atmospheric pressure. Such arrangements can reduce noise, size and vibration levels associated with conventional load lock pumps.

CLAIMS

1. A vacuum pump comprising a multi-stage centrifugal compressor mechanism for receiving fluid to be pumped and exhausting pumped fluid substantially at atmospheric pressure.

2. A vacuum pump according to Claim 1, comprising a pump housing and a rotatably mounted drive shaft, each stage of the compressor mechanism comprising a respective impeller mounted on the drive shaft and a respective stator located on the inner wall of the pump housing.

3. A vacuum pump according to Claim 2, wherein each impeller has on one side thereof a plurality of vanes extending between the inner periphery and the outer periphery thereof.

4. A vacuum pump according to Claim 3, wherein each vane follows a curved path.

5. A vacuum pump according to any of Claims 2 to 4, wherein each stator comprises a disc integral with a respective part of the pump housing.

6. A vacuum pump according to any of Claims 2 to 5, wherein each stator comprises a plurality of cooling fins on one side thereof.

7. A vacuum pump according to Claim 6, wherein, for each stage, the cooling fins are provided on the side of the stator facing away from the impeller.

8. A vacuum pump according to any of Claims 2 to 7, wherein the drive shaft is supported at the ends thereof by lubricant-free bearings.

9. A vacuum pump according to Claim 8, wherein the lubricant-free bearings are magnetic bearings.

10. A vacuum pump according to any of Claims 2 to 9, wherein each stage comprises a fluid chamber within which the impeller rotates during use of the pump.

11. A vacuum pump according to Claim 10, wherein at least one of the fluid chambers comprises an inlet through which a first fluid stream enters the chamber, an outlet through which pumped fluid is exhausted from the chamber, and, intermediate the inlet and the outlet, a fluid port through which a second fluid stream enters the chamber, the pump comprising means for controlling the flow of fluid through the fluid port and thereby control the rate of flow of fluid through the outlet to a subsequent stage of the compressor mechanism.

12. A vacuum pump comprising a multi-stage centrifugal compressor mechanism, at least one stage of the compressor mechanism comprising a fluid chamber having an inlet through which a first fluid stream enters the chamber, an outlet through which pumped fluid is exhausted from the chamber, and, intermediate the inlet and the outlet, a fluid port through which a second fluid stream enters the chamber, the pump comprising means for controlling the flow of fluid through the fluid port and thereby control the rate of flow of fluid through the outlet to a subsequent stage of the compressor mechanism.

13. A vacuum pump according to Claim 11 or Claim 12, comprising means for conveying the second fluid stream to the fluid port.

14. A vacuum pump according to Claim 13, wherein the conveying means is arranged to return a stream of pumped fluid to the chamber through the fluid port.

15. A vacuum pump according to Claim 14, wherein the conveying means comprises a fluid passage extending between stages of the compressor mechanism.

16. A vacuum pump according to Claim 15, wherein the fluid passage extends between fluid ports of adjacent stages of the compressor mechanism.

17. A vacuum pump according to Claim 16, wherein the fluid passage extends through the pump housing.

18. A vacuum pump according to Claim 16, wherein each chamber comprises, intermediate the inlet and the outlet, a first fluid port through which pumped fluid enters the chamber and a second fluid port through which pumped fluid exits the chamber, the conveying means passing between the first fluid port of one chamber and the second fluid port of a second chamber.

19. A vacuum pump according to Claim 18, wherein the fluid passage passes through means axially separating adjacent chambers of the compressor mechanism.

20. A vacuum pump according to Claim 19, wherein the axially separating means comprises one or more discs mounted on the inner wall of the pump housing.

21. A vacuum pump according to any of Claims 18 to 20, wherein the first and second fluid ports are co-axial.

22. A vacuum pump according to Claim 13, wherein the conveying means is arranged to convey a stream of purge gas to the chamber through the fluid port.

23. A vacuum pump according to Claim 22, wherein said purge gas comprises one of air and an inert gas.

24. A vacuum pump according to any of Claims 13 to 23, wherein the control means comprises valve means in fluid communication with said conveying means.

25. A vacuum pump according to Claim 24, wherein the valve means comprises a spool valve.

26. A vacuum pump according to any of Claims 12 to 25, comprising means for cooling the second fluid stream.

27. A vacuum pump according to any preceding claim, comprising a cooling jacket extending about at least the exhaust stages of the compressor mechanism.

28. A vacuum pump according to any preceding claim, comprising, upstream from the centrifugal compressor mechanism, a multi-stage molecular drag mechanism.

29. A vacuum pump comprising a multi-stage centrifugal compressor mechanism and, upstream therefrom, a multi-stage molecular drag mechanism arranged to receive fluid to be pumped and to exhaust pumped fluid to the radial flow compressor mechanism.

30. A vacuum pump according to Claim 28 or Claim 29, wherein the molecular drag mechanism comprises a multi-stage Holweck mechanism having a plurality of channels arranged as a plurality of helixes.

31. A vacuum pumping arrangement comprising a booster pump in series with a backing pump, wherein the booster pump comprises a vacuum pump according to Claim 29 or Claim 30.

32. A vacuum pumping arrangement comprising a booster pump in series with a backing pump, wherein the backing pump comprises a vacuum pump according to any of Claims 1 to 27.

33. A vacuum pumping arrangement comprising a booster pump in series combination with a backing pump, wherein the booster pump comprises a multi-stage molecular drag mechanism and a multi-stage centrifugal compressor mechanism, and the backing pump comprises a multi-stage centrifugal compressor mechanism.

34. A vacuum pump substantially as herein described with reference to the accompanying drawings.

ABSTRACT

Two vacuum pumping arrangements are described for evacuating a load lock chamber. In the first arrangement, a single pump comprises a multi-stage molecular drag stage and a multi-stage centrifugal compressor mechanism exhausting pumped fluid at atmospheric pressure. In the second arrangement, a booster pump is provided in series with a backing pump. The booster pump is similar to the pump of the first arrangement, but with a reduced number of compressor mechanism stages. The backing pump also comprises a multi-stage centrifugal compressor mechanism exhausting pumped fluid at atmospheric pressure. Such arrangements can reduce noise, size and vibration levels associated with conventional load lock pumps.

(figure 1)

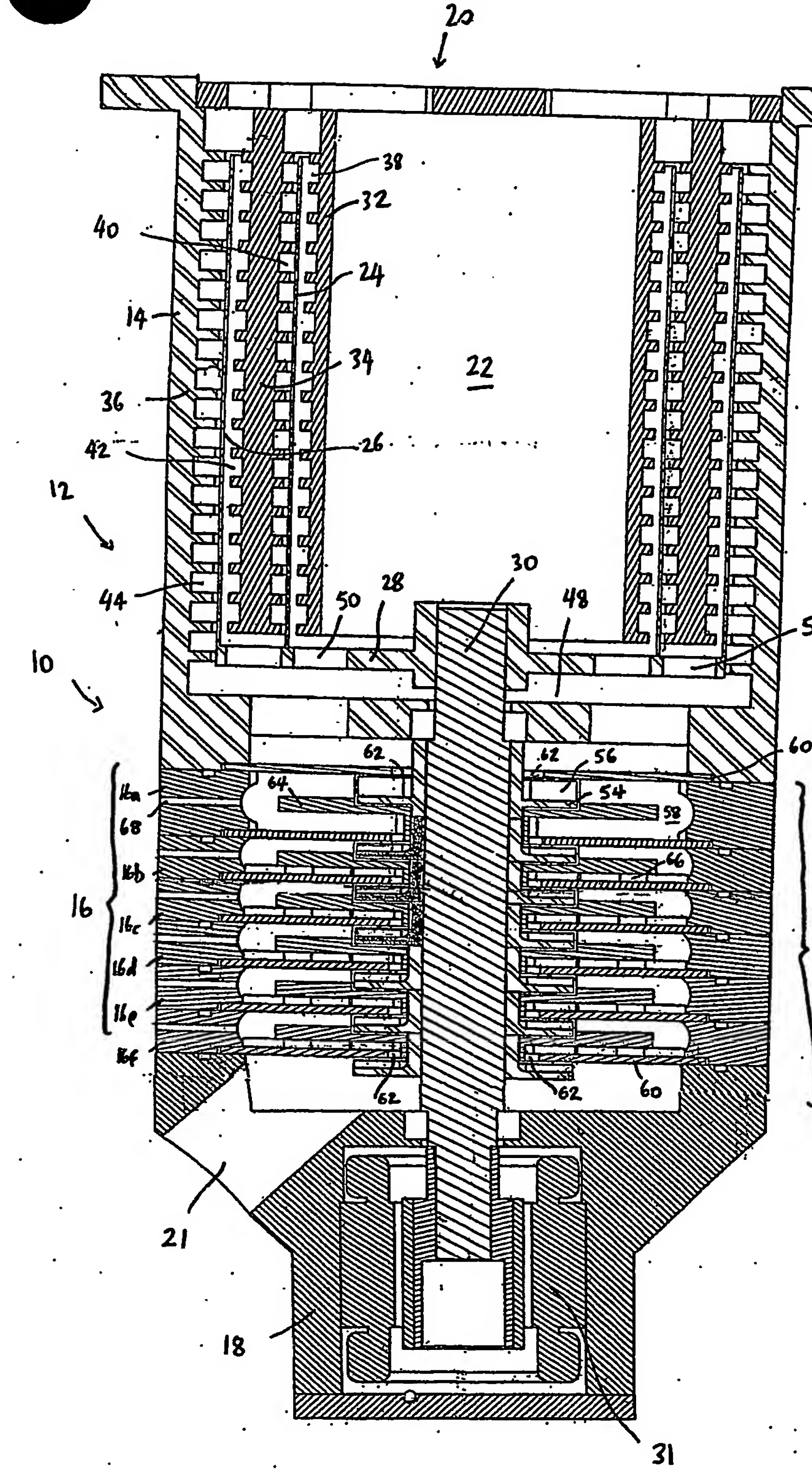
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FIG. 1

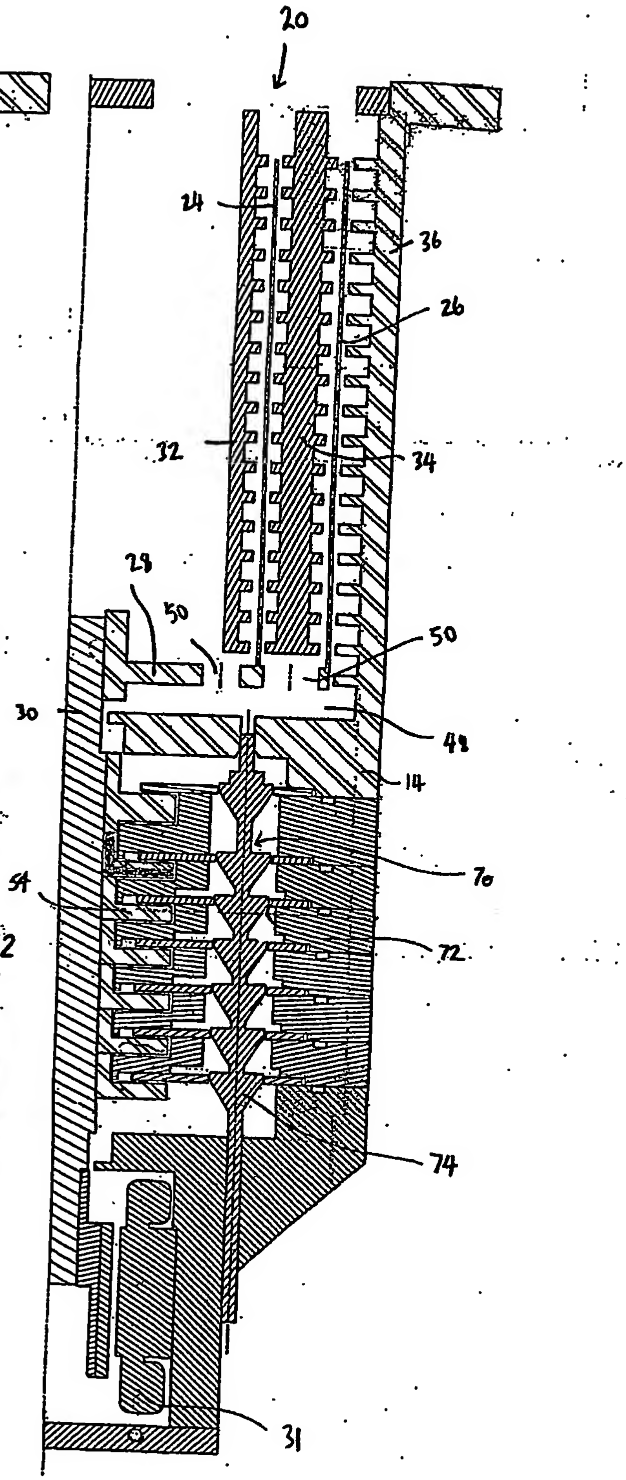
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FIG. 2

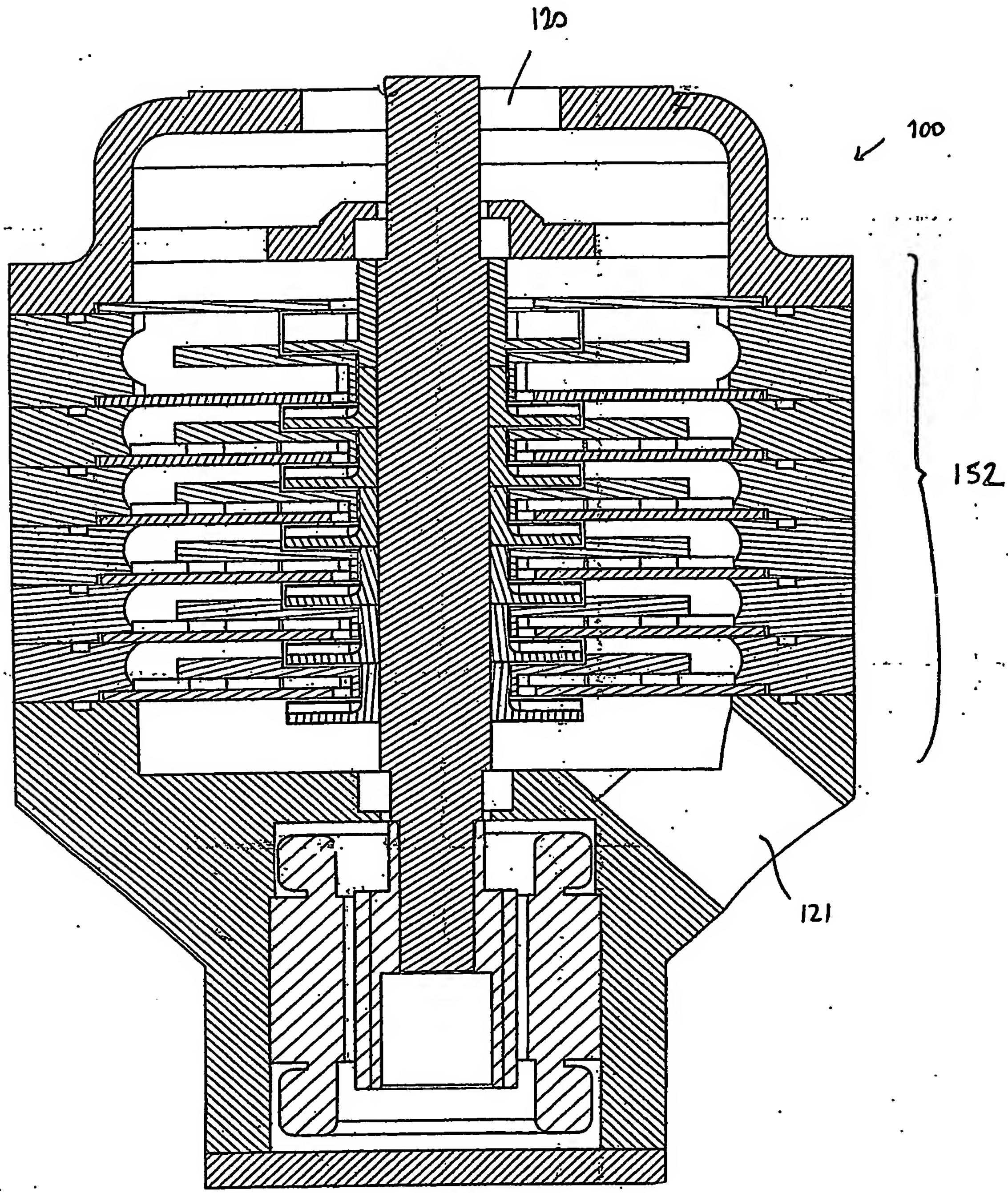

FIG. 3